PERMO-CARBONIFEROUS GLACIAL DEPOSITS OF SOUTH AMERICA

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INTRODUCTION

The proofs of tremendous glaciation at the end of the Carboniferous have been given in great detail from South Africa and Australia and less fully from India; but comparatively little has been reported regarding Permo-Carboniferous glaciation in South America. Having seen something of the tillites and glaciated rock surfaces of typical localities in the first three regions, it seemed desirable to visit the less-known glacial deposits of South America. During the past summer this has been accomplished, and it is proposed to give in this paper a brief account of what was observed.

The probability that certain Carboniferous or Permian bowlder conglomerates with a matrix of shale in southern Brazil were of glacial origin was recognized by Orville Derby as early as 1888;[1] but no striated stones were found, and the evidence seemed scarcely sufficient to establish the point. In 1907 and 1908 I. C. White and David White made it almost certain that the widespread bowlder conglomerates were glacial, the latter showing that the accompanying flora, as collected during I. C. White's examination of the coal deposits of southern Brazil, was identical with floras in a similar relation in South Africa and India.[2] Still the final proof, the finding of striated stones, was lacking.

In 1908 J. B. Woodworth studied the southern Brazilian tillites, finding striated stones plentiful and making their glacial origin absolutely certain. His report on the field work accomplished, with

[1] Orville Derby, "Spuren einer carbonischen Eiszeit in Süd Amerika," *Neues Jahrb. für Min.*, etc., Band II (1888), 175.

[2] David White, "Permo-Carboniferous Climatic Changes in South America," *Jour. Geol.*, XV (1907), 615–33; and I. C. White, in his *Relatorio Final on the Brazilian Coal Fields*, 1908, pp. 11–119.

the aid of two young Brazilian geologists, Eusebio Oliviera and Juvenal Pacheca, is admirable and has served as guide in a portion of my own work.[1] In the following year H. Bross confirmed his conclusions, finding striated stones near Itararé.[2]

Up to 1911 Permo-Carboniferous tillite had been reported from southern Brazil only; but in that year T. G. Halle described tillite of the same age from the Falkland Islands, which may be looked on as belonging to the South American region.[3] In 1912 tillite with polished and striated stones, including bowlders up to 1.5 meters in diameter, was described by C. Guillemain, from Uruguay;[4] and in 1913 J. Keidel announced the finding of tillite of this age in southern and western Argentina in a paper read before the Twelfth Geological Congress in Toronto; while in 1916 he gave an excellent and full account of the tillite at Sierra de la Ventana in southern Argentina.[5]

From this outline of the literature on the Permo-Carboniferous glaciation in South America it will be seen that our knowledge of the distribution of the tillite is rapidly growing, extending now to three countries, and that this glacial formation is widely spread in southern Brazil and perhaps also in Argentina. In Brazil the excellent field work of Oliviera and Pacheca is constantly extending the known area of glaciation, so that in this respect South America may soon rival South Africa and Australia and surpass India.

It was planned to visit localities for tillite in several parts of Brazil and at Sierra de la Ventana in Argentina, and these plans were carried out successfully, largely through the help and advice of Pacheca in São Paulo and of Keidel at Buenos Aires. I am specially indebted to Dr. Pacheca, who has mapped the tillite in detail in the state of São Paulo, and who showed me a number of

[1] J. B. Woodworth, *Bull. Mus. Comp. Zoöl., Harvard,* LVI, No. 1, Geol. Series, X. *Geol. Exped. to Brazil and Chile.*

[2] H. Bross, "Glacial Spuren in Parana," *Cent. Bl. für Min.*, etc., 1909, pp. 558–61.

[3] T. G. Halle, *Geol. Mag.*, N.S., V, 264–65; also *Bull. Geol. Inst., Univ. Uppsala,* XI, 144–56.

[4] C. Guillemain, *Neues Jahrb. für Min.*, etc., Beil. Band XXXIII, 208–64.

[5] J. Keidel, *Comptes Rendus*, pp. 676–80; also in *La Geologia de las Sierras de la Provincia de Buenos Ayres*, Tomo XI, No. 3, *Anales del Ministerio de Agricultura of the Argentine Republic*, 1916.

typical outcrops in the field. Through his courtesy and kindness I had an admirable introduction to the Paleozoic bowlder clays of Brazil.

TILLITES IN THE STATE OF S˜O PAULO

In tropical Brazil, with its moist, hot climate, weathering goes to great depths, and even in the southern parts of the country, where the climate is warm temperate, the products of decay mantle most of the surface, so that fresh outcrops of rock are seldom to be found under natural conditions. On this account the most satisfactory points for geological work are cuttings along the railways or depressions where roads ascend hills and the wheels of vehicles have worn their way downward. To an observer fresh from parts of North America where the Pleistocene glaciation has left clean surfaces of almost unchanged rock this is most disconcerting, and it takes a little time to adjust one's self to the new conditions. The working out of field relations is greatly hampered by the products of weathering, which usually hide even the weathered rock and may accumulate to considerable depths on slopes and in valleys.

Under Dr. Pacheca's guidance a number of railway and road sections were visited to the north of the city of São Paulo, the first region being near the thriving city of Campinas. In railway cuttings two or three kilometers from the city, tillite rests upon gneiss, probably of Archean age, two mounds of the gneiss rising with rounded forms suggesting *roches moutonnées;* but unfortunately weathering has gone so far at the contact as to destroy any smoothed or striated surface that may have existed in the beginning. According to Dr. Pacheca this is almost the only example known in Brazil of tillite resting on what must have been a scoured surface of solid rock.

The tillite is weathered and scarcely harder than certain Pleistocene tills, though its yellow or red or chocolate-brown color is unlike the customary bluish gray of North American bowlder clay. Striated stones were not found here, though the general appearance of the rock was that of tillite, some of the more resistant stones inclosed in it, such as quartzite and granite, still showing subangular forms and smoothed surfaces. Overlying the tillite are shaly or sandy beds, distinctly stratified and including some-

times a thin layer of conglomerate, the series being closely related to the tillite and sometimes interstratified with it, as in many sections of Pleistocene glacial deposits.

The next point visited was near Capivary, reached by a narrow-gauge railway from Campinas, where a delightful walk of 18 kilometers disclosed excellent sections of tillite containing typically shaped and sometimes striated stones (Fig. 1) including

FIG. 1.—From Capivary, São Paulo, Brazil

bowlders of sandstone, quartzite, conglomerate, and granite occasionally reaching a diameter of one meter. The coarse conglomerate forming some bowlders quite suggests the Huronian tillite of Cobalt, Ontario, and their source in Brazil is unknown. The tillite has a thickness of three or four meters and rests on soft, stratified sandstone or sandy shale sometimes cross-bedded. In one place it is covered by a sheet of trap mostly weathered into the bright-red "terra roxa" which forms the best soil for coffee and sugar plantations.

A visit was made to a section near Villa Raffard, about four kilometers southwest of Capivary, to see some large bowlders of

the ancient conglomerate, including pebbles of jasper, another feature suggesting the Huronian rocks of Ontario. These conglomerate bowlders have also been mentioned and figured by Woodworth.

In several places shales accompanying the tillite have been thrown into folds a few meters in dimensions, either by ice-thrust at the time of glaciation or by later compression. Over the tillite in places a brown fine-grained unstratified material, pierced by worm or root holes, stands up as low cliffs and suggests an ancient loess. At one point on the railway near Capivary (kilometers 160–61) shales beneath the tillite appear to have been crumpled and then truncated, showing an unconformity between the tillite and the soft sediments beneath; and some soft sandstone bowlders in the tillite are quite like an irregularly bedded sandstone frequently found in the same position, suggesting the same relationship.

The fresh tillite is often solid enough to make vertical faces in cuttings and shows spheroidal shapes when weathering has begun. Ultimately the rain breaks it down into slippery clay, gray or yellowish or red in color, strongly suggesting a rain-crumbled Pleistocene till. Near the small station Elias Fausto, Dr. Pacheca has found tillite inclosing very large granite bowlders, one partly disclosed measuring $3 \times 3 \times 2$ meters, and looking like one of the Iowan bowlders of the Western states.

My last excursion under Dr. Pacheca's guidance was to Limeira, 50 kilometers northwest of Campinas, where a round of 21 kilometers was made over country roads giving an opportunity to see typical bowlder clay extending over many square kilometers of gently rolling country. The tillite is usually chocolate colored and in places reaches a thickness of 25 meters, while in other places it has been cut through by the stream valleys. In the steep walls of a sunken road leading out of the town plenty of well-striated stones were found, and except for the prevailing red color and a little greater hardness the outcrops reproduce perfectly the features of a region of bowlder clay in North America. It was hard to believe that the rock was as old as the Permian.

Limeira is about in latitude $22\frac{1}{2}°$, a degree within the tropics, so that in Brazil, as in India and Australia, the ancient ice-sheet reached much nearer to the equator than any Pleistocene ice-sheet.

It is estimated by Drs. Florence and Pacheca, of the Geological Survey of the State of São Paulo, that the outcrops of tillite extend from northeast to southwest for 500 kilometers, with a width of from 50 to 100 kilometers; and it must be added that the tillite follows the gentle northwestward dip of the rocks of the region and probably extends far beneath the Triassic beds in that direction. It is evident that one is dealing with deposits formed by a great ice-sheet spread out over a peneplained surface and not with the results of mountain glaciers.

TILLITE IN STATES SOUTHWEST OF SÃO PAULO

After the admirable introduction to the study of Brazilian glacial deposits provided by the kindness of Dr. Pacheca there was little difficulty in recognizing the characteristic appearance of the tillite, and on the journey by rail from São Paulo to Montevideo in Uruguay some of the localities described by Woodworth were visited, the first just beyond the southwestern boundary of the state of São Paulo between Itararé and Sengens. In railway cuts near Sengens, Woodworth had found striated stones and large bowlders of sandstone; and a walk along the railway between the two stations proved extremely interesting.[1] Following the crooked narrow-gauge railway from Sengens northeast toward Itararé tillite is seen for eleven kilometers (from km. 241 to km. 230) resting usually on sandstone, occasionally with a hummocky surface and in one case with a suggestion of furrowing in a direction from southeast to northwest or vice versa. The sandstone is still soft, and when the tillite was deposited may have been softer, so that large blocks could easily be lifted and inclosed in the glacial materials. In addition to these masses of local rock there are quite large bowlders of shale and of granite, and a multitude of smaller stones, many of a harder sandstone than the underlying rock, and a few of quartzite. The tillite varies in thickness, sometimes reaching ten meters. Parts of it near kilometer 241 have been more or less

[1] See Woodworth's *Report*, p. 62 and Pls. xxi and xxii.

pushed and crumpled, and not far to the northeast is the great fault and escarpment mentioned by Woodworth.

The best display of tillite is about at kilometer 235, where the smaller stones are very frequently striated, more so than in any other till I have seen, whether Pleistocene or older. Many of the glaciated stones show not only "soles" but well-defined facets, as if they had been firmly held till a face was ground flat and then adjusted at another angle, resulting in another flat face. These facets sometimes come together sharply. In early days similar faceted stones from the Permo-Carboniferous tillite of India attracted attention. It would seem as if the Permo-Carboniferous ice-sheets held their imbedded stones more firmly than those of the Pleistocene. Why? Were their bases colder or was there a greater thickness of ice, giving a stronger pressure?

As may be seen from the train, tillite extends several kilometers on the route southwest; but the next stop was made at Ponta Grossa, midway across the state of Parana, where I. C. White had described outcrops of glacial conglomerate.[1] On the side of the ridge on which the town is built, cuttings, made for streets and for drainage, disclose reddish, sandy glacial deposits containing subangular stones of various kinds, a few of which were found to be striated. A fairly good section is seen also on a road leading into the country. Above the tillite there is a sheet of trap weathering into a very red soil, and beneath it sandstone followed by black shale from which Devonian fossils are reported.

A visit was made also to Serinha, 70 or 80 kilometers to the southeast, where Woodworth suspected an older tillite. Typical bowlder clay is passed between Palmeira and Nova Restingua and may be seen at Porto Amazonas. There is a rapid descent from Palmeira to Serinha, which is in a deep river-valley at the base of sandstone cliffs. The tillite here takes the form of blue or yellow shale, readily weathering to clay, containing subangular stones, chiefly sandstone, quartzite, and granite. No striated stones were found, but the bed looks like a glacial deposit. It is overlain by 200 feet of firm sandstone resembling the rock found beneath the tillite at higher levels. Beyond this fact no clue to its age was

[1] I. C. White, *Relatorio Final on the Brazilian Coal Fields*, 1908, p. 51.

observed. The whole series of rocks, including the two tills, seems to lie nearly horizontal, doubtless with a gentle dip northwestward following the regular trend of the stratification in southern Brazil. The tillite at Serinha looks no older than that described before, and may represent merely a Carboniferous forerunner of the more important glaciation to follow.

Southeast of Ponta Grossa the railway lies too far west to give opportunities of observing the glacial deposits, passing over trap-sheets, Triassic sandstones, etc.; but I. C. White's account of the bowlder conglomerates associated with a low grade of coal and Permian plants in the state of Santa Catharina, e.g., at Orleans, shows that tillite continues to latitude 28°.[1] His map of the Tubarão series, which includes the Orleans glacial conglomerate, extends the tillite to the southern end of Brazil, in Rio Grande do Sul, though his account does not specially mention bowlder conglomerates as having been observed in that part of the country.

Guillemain, by finding tillite with striated stones at Fraile Muerto in northern Uruguay, not far from the boundary of Brazil, as noted in the introduction, continues the region of glaciation still farther to the south. Including the 500 kilometers reported from São Paulo this gives a length of about 1,500 kilometers from northeast to southwest, running in latitude from $22\frac{1}{2}°$ to about $32\frac{1}{2}°$. The tillite has not yet been found to outcrop continuously for this long distance, but the known localities are sufficiently numerous to make its continuity highly probable. Its known width is estimated at from 50 to 100 kilometers in São Paulo, but it is unknown how far it extends beneath the Triassic sediments and trap-sheets to the northwest.

TILLITE IN SIERRA DE LA VENTANA

There is a long gap between the Permo-Carboniferous deposits of Brazil and northern Uruguay and the nearest outcrops of tillite discovered in Argentina, which are in the Sierra de la Ventana not far from Bahia Blanca. Dr. J. Keidel, chief of the Geological Section of the Argentine Survey, was good enough to plan an excursion to this locality for me. A rail journey of 537 kilometers

[1] I. C. White, *Relatorio Final on the Brazilian Coal Fields*, 1908, pp. 11–13 and 51.

southwest from Buenos Aires brings one to the small station among the hills, after passing a vast stretch of prairie-like pampas with few or no outcrops of rock. The Sierra rises as rocky ridges with deep valleys between, one of them followed by the river Sauce Grande and others by its tributaries.

The railway crosses the river just south of the station and follows up the valley of a small stream in the Arroyo Negro. The best exposures of tillite are found in the railway cuttings along the Arroyo within seven kilometers of Sierra de la Ventana, and these will be described first.

The unweathered tillite is dark, bluish gray and entirely different in appearance from the usually red or brown and much-decayed tillite of Brazil. The rock is hard and shows some slaty cleavage, and the stones scattered through it are often a little squeezed or broken and slightly step-faulted. The weathered tillite is greenish or yellowish and crumbles somewhat readily, setting free the inclosed stones, but from the unweathered rock it is difficult to extract them unbroken. The fresh tillite is very like that from some outcrops of the Dwyka in South Africa, where the rock has undergone squeezing and distortion in mountain-building operations; and it closely resembles the Huronian tillite of Cobalt and might easily be taken for it in hand specimens.

The pebbles and bowlders inclosed include several species of rocks, granites and hard sandstones being commonest. They are seldom more than half a meter in diameter and have the characteristic shapes of glaciated stones. A considerable number have well-striated surfaces and are typical products of ice action.

In some of the cuttings cross-bedded quartzite and more or less water-formed conglomerate occur also, apparently interbedded with the tillite; and in several places quartzite overlies the tillite conformably. The base of the tillite was not seen in the railway cuttings, and a search was made for it to the north, where a small stream flows toward the Sauce Grande, but in vain. On this stream the tillite has been squeezed into schist conglomerate with a marked cleavage, reminding one of the Temiscaming and Doré conglomerates of Ontario. A search still farther north showed no solid rock for several kilometers until the base of the northern range

of hills was reached, where quartzite, mica schist, and slate were encountered.

Sections were examined a few kilometers up the river from the station and several fresh-looking outcrops of tillite were found at the water's edge. Ascending the slopes from such outcrops one finds weathered tillite for a few hundred yards, then a cliff of tillite, followed by a covered belt where only quartzite pebbles can be seen for a height of about 15 or 20 meters. A second cliff of tillite reaches 85 meters above the river and is followed by quartzite to the top of the ridge. The lower bed of quartzite seems to be interglacial, corresponding to the band of quartzite and water-formed conglomerate seen in the railway cuttings.

A section a kilometer or two down the Sauce Grande shows no base to the tillite, which has a thickness of 90 meters, as determined by aneroid, and is covered by quartzite including a band of tillite. None of the sections was entirely satisfactory, since on the gentler slopes the solid rock is more or less hidden; but the thickness of the glacial beds seems to be not less than 60 meters and may be much more than that.

An excellent account of the glacial deposits of Sierra de la Ventana is given by Keidel in *La Geologia de las Sierras de la Provincia de Buenos Ayres* (1916), as mentioned in the introduction to this paper; and the statement is made that the origin of a number of the inclosed bowlders is unknown. Keidel puts stress on the resemblance of these deposits to the Dwyka, but gives no proofs of their age except that they are later than the Devonian, as shown by the inclusion of pebbles of limestone with Devonian fossils. The hard and somewhat metamorphosed character of the rock, which seems to suggest a greater age, is to be accounted for by the action of orogenic forces. One of Keidel's plates represents the tillite as somewhat folded in a way that would add to the apparent thickness of the bed, but in my own field work no clear evidence of folding was seen, though compressive action was evident.

TILLITE NEAR SAN JUAN IN WESTERN ARGENTINA

Following a plan suggested by Dr. Keidel an excursion was made to exposures of tillite in western Argentina somewhat south of

San Juan. The nearest point to the outcrops on the railway between San Juan and Mendoza is at Paradero, kilometer 489. The railway traverses a desert country covered with sand and stones with isolated hills of rock not far to the east and the loftier Chico de Zonda, a range of foothills of the Andes, about eight kilometers to the west, as shown on Stappenbeck's geological map of the region. Walking westward over the desert from the railway there is a gentle rise for two or three kilometers, followed by low ridges between profound ravines, apparently cut by temporary streams due to cloud-bursts in the mountains. At about five kilometers west there are steeply tilted red shales dipping westward, followed by hills of a green, basic eruptive, greatly weathered, and then high cliffs of gray limestone. In the latter rock, fragments of crinoids and a syphon of orthoceras were found. It is indicated on the map as Silurian.

A little to the south of this section, where a narrow valley penetrates rugged hills, a greenish-gray shaly or slaty rock occurs, crumbling to fine débris on the surface, and including one or two bands of dark-brown pebbles and larger stones (Fig. 2). Most of the stones are fairly well rounded, as if rolled on a beach or in a river, and many have been broken and recemented. Frequently they have been broken again where they lie on the surface, probably by alternations of heat and cold.

A number of these stones are striated, often on more than one face. The largest seen was half a meter or somewhat less in diameter and was strongly scored. The stones are mainly basic eruptives, quartzite or limestone, the last too much attacked to show marks of glaciation. These stones appear to have been imbedded in the weathered, shaly rock, and in a ravine near by a few isolated ones are found still inclosed. The series appears to be tilted, but the dip and the limits of the bowlder bed could not be sharply determined, and in places two bowlder beds occur separated by a few meters of shale. These outcrops of loose, striated stones were followed for nearly a kilometer in a southerly direction, running parallel to the strike of the rocks in the foothills.

Somewhat to the southwest, where the narrow valley is steep-walled and approaches the cliffs, a side ravine disclosed an abso-

lutely different section, in which a bowlder conglomerate rudely stratified in parts rises as a ridge about 30 meters high. This is of a kamelike character and includes sand, gravel, and stones of all sizes up to a meter in diameter. They are often rounded, but may be of various shapes and consist of many kinds of rocks—granite,

FIG. 2.—From tillite south of San Juan, Argentina

gneiss, quartzite, vein quartz, sandstone, and limestone having been observed. Striated stones seem rare, only one poorly marked one having been found. It may be remarked, however, that in Pleistocene kames also it is unusual to find distinctly striated stones. Beneath the kamelike bed there are two or three meters of sandstone, and across a wide valley to the south a cliff shows six or seven meters of the conglomerate underlying, apparently

conformably, a hundred meters or more of sandstone with a westward dip.

The two types of deposit just described are as different as possible, though both seem to be glacial, but I was unable to determine how they are related to one another, since there has been folding, faulting, and squeezing during the formation of the mountain range, rendering the relationships complicated.

Before leaving Buenos Aires, Dr. Keidel had referred to two tillites, a lower and an upper, corresponding probably to the two deposits just described. He mentioned also that near the lower tillite Talchir plants had been found, and some distance farther south Kharbari plants, giving a clue to the age of the deposits. He has also found tillite to the north of San Juan, reaching in one place latitude 28°, and has discovered a striated surface of Devonian limestone beneath the tillite. Specimens of the tillite and of the glaciated surface are to be seen in the Museum of the Survey on Calle Maypu in Buenos Aires. His account of the very interesting glacial deposits in the western foothills of the Andes must be awaited for details as to their general features and relationships, but I am able to confirm his statements as to the glacial character of the beds so far as seen by myself.

CONCLUSIONS

From the descriptions given it will be seen that there are three widely separated regions of known Permo-Carboniferous glaciation in South America, the deposits differing much in appearance and lithological character, but all showing plainly the effects of ice action. The Brazilian tillites are the most widely distributed and the least changed. They occur along the dissected edge of a tableland rising several hundred meters above sea-level and dip gently inland beneath sandstones and trap-sheets of the early Mesozoic. One or two diamond-drill cores prove that the tillite extends for 50 kilometers or more beneath the Triassic beds, but how much farther they go in that direction is unknown. There can be no doubt that they once reached farther seaward, so that the original ice-covered area must have been much greater than the present known area of tillite. As marine fossils have been found by Oliviera interbedded with the tillite on the Rio Negro in the state

of Parana,[1] we may conclude that the region was at that time not a tableland but a comparatively low plain. In any case the whole character of the widespread, almost flat sheet of tillite in southern Brazil is such as must have resulted from ice action of the continental type. Mountain glaciers could not have provided so extensive, uniform, and relatively horizontal a deposit as the Brazilian geologists have found.

From what center the ice spread out is not known, though the numerous bowlders of granite and gneiss suggest a motion inland from the belt of Archean along the Atlantic coast. In that case the ice-sheet must have extended far toward the southeast, perhaps beyond the present edge of the continent. However, there are granites and gneisses farther west, and outcrops of these rocks which existed in Carboniferous times may lie buried under later deposits toward the west or north. The bowlders of ancient conglomerate containing jasper may some day be traced to their source, giving evidence of the direction in which the ice moved.

As to the tillites of the Rio Sauce Grande and of the belt along the foothills of the Andes near San Juan, the areas known to be covered by them are so small that local mountain glaciation might perhaps account for them; though the fact that tillite of the same age occurs on the Falkland Islands and that a great ice-sheet covering many thousands of square miles reached sea-level a few hundred miles to the north or east suggests that a very large part of South America must have been ice covered. It is not unlikely that the areas of ice action coalesced to form a single great sheet 1,300 miles or more in diameter and covering hundreds of thousands of square miles, something comparable to the vast continental ice-sheets of Europe or North America in the Pleistocene. The northern edge of this ice-sheet reached at least one degree into the tropics in Brazil; and this occurred, not on high mountains, but on comparatively low ground, as shown on a former page.

Recent advances in the study of the South American Permo-Carboniferous glacial deposits bring that continent into the same rank as South Africa and Australia with respect to the area then covered by ice, while India has been much surpassed. The magnitude of the geological problem involved is growing from year to

[1] Woodworth's *Report*, p. 29.

year, and the difficulty of accounting for such tremendous climatic changes is by no means lessening. The fact that the most extensive ice-sheets were in the Southern Hemisphere and that India only in the Northern Hemisphere shows important glaciation at the end of the Carboniferous forms one of the puzzling features of the problem. The idea that a change in the position of the poles could account for Permo-Carboniferous ice-sheets has been completely set aside by the discoveries in South America, since with the South Pole planted in the middle of the Indian Ocean southern Brazil would have been within the tropics.

The theory of glaciation due to elevation is disproved also by the evidence from Australia and South America, showing that the ice-sheets reached sea-level; and in any case it is inconceivable that such vast areas could all be elevated the necessary thousands of feet at the same time. Even if they were sufficiently elevated to give the required temperature, a large enough supply of moisture could hardly be arranged for on the greatly enlarged continents which this implies. The high tableland of the Andes is arid or semi-arid at present, and even the loftier peaks usually show little snow and few and small glaciers. It is evident that elevation alone will not account for the millions of square miles of *nevé* and ice-fields which must have covered much of India, Africa, Australia, and South America.

The most satisfactory theory is that of refrigeration due to changes in the earth's atmosphere; but even this fails to explain why Europe, Northern Asia, and North America should have been so little affected when great regions in other parts of the world were powerfully glaciated. One would expect that the change of climate affecting the tropics in India, Australia, and South America, and probably also in Africa would have been felt everywhere. It may be, however, that while the refrigeration was universal the supply of moisture necessary to form glaciers was lacking in Northern Asia, Europe, and North America. They may have had no ice-sheets for the same reason that Siberia was left uncovered with ice in the Pleistocene Ice Age; because the position of the open seas and the direction of the atmospheric circulation made them relatively dry regions with little snowfall.